Somatosensory-Evoked Potential Monitoring

6

Marc R. Nuwer, Lara M. Schrader,
and Pedro Coutin-Churchman

Introduction

Somatosensory-evoked potentials (SEPs) are an excellent modality for spinal cord monitoring during surgery. They test much territory, including peripheral, spinal, brain stem, thalamic, and cortical levels of lemniscal sensory pathways. SEPs are used to monitor both spinal cord and cerebral injury during various types of surgery.

SEP intraoperative monitoring (IOM) is specific for the dorsal column-medial lemniscal (DCML) pathway but infers protection for other pathways as well. Stimulation of mixed peripheral nerves of the upper and/or lower extremity is accompanied by recording from various anatomic generators along the DCML pathway. The most common site for lower extremity stimulation is at the posterior tibial nerve (PTN) at the ankle. Alternate stimulation sites include the PTN in the popliteal fossa (behind the knee) or the common peroneal nerve at the knee. Recording sites include popliteal fossa, lumbar spine, a cervical site, and a cortical site from the scalp. For upper extremity SEP monitoring, the median or ulnar nerves at the wrist are most commonly stimulated with recording sites over the brachial plexus (at Erb's point), cervical spine, and scalp. Figure 6.1 shows an example of stable normal SEPs during a routine case.

SEP IOM is used to provide an alert to the surgeon about potential neurological complications. This is provided in real time so that an intervention could prevent an adverse outcome. SEP IOM also provides the surgeon with a reassurance that surgery is proceeding without complication. This reassurance gives the surgeon confidence to complete a procedure or to be more aggressive with correction, tumor removal, etc., thereby possibly making the surgery more successful. It is important that information (especially alerts) is given to the surgeon in real time. This allows correlation of the alert with surgical steps that may be undone in order to reverse the change.

Stimulation

SEPs are commonly used in the outpatient lab. In the operating room, the techniques are very similar. Table 6.1 summarizes the parameters used for intraoperative SEPs.

M. R. Nuwer (✉) · L. M. Schrader
UCLA School of Medicine, Department of Neurology, Los Angeles, CA, USA
e-mail: MRN@UCLA.edu

P. Coutin-Churchman
Ronald Reagan UCLA Medical Center, Department of Clinical Neurophysiology, Los Angeles, CA, USA

S. F. Davis, A. D. Kaye (eds.), *Principles of Neurophysiological Assessment, Mapping, and Monitoring*, https://doi.org/10.1007/978-3-030-22400-4_6

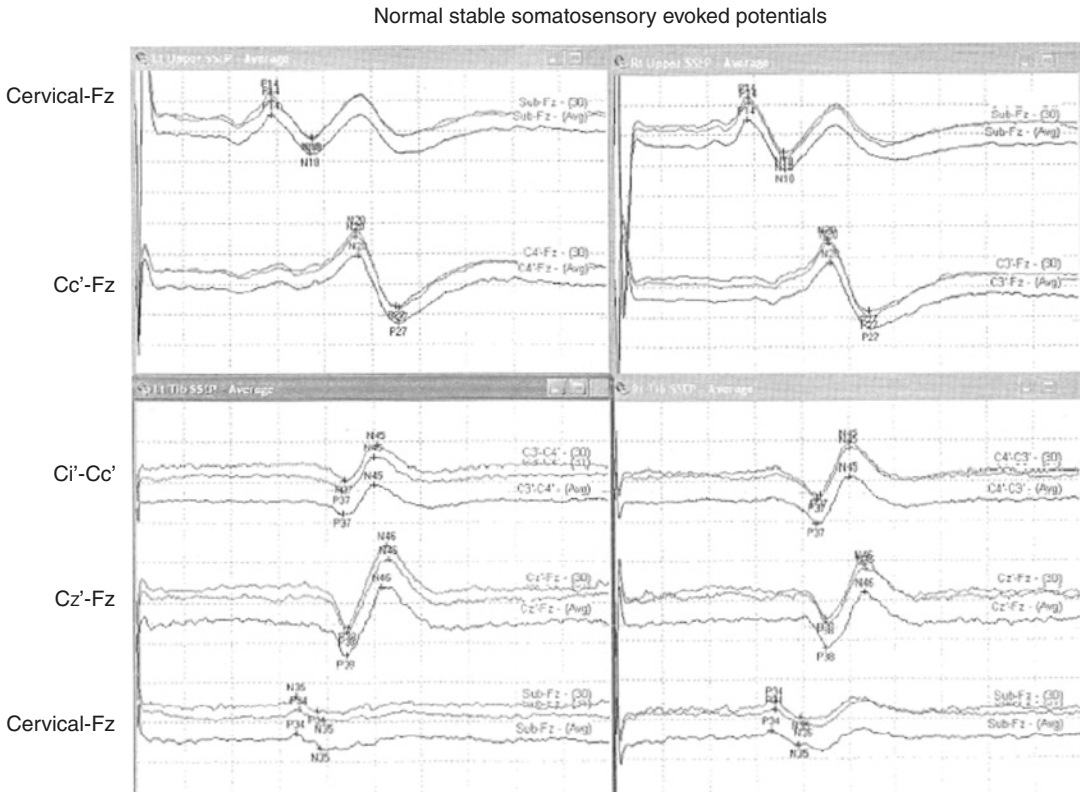

Fig. 6.1 Normal stable SEPs from the left and right median and left and right posterior tibial nerves. (From UCLA Department of Clinical Neurophysiology, with permission)

Sites

For the lower extremities, electrical stimulation to the *PTN* is applied to the ankle. That nerve is superficial and located just posterior to the medial malleolus. For some patients, the *peroneal nerve* is chosen instead. That nerve can be found superficially lateral to the knee, just below the fibular head. That site is useful especially in patients with a peripheral neuropathy, such as diabetics, and in the elderly. Upper extremity stimulation is delivered to the *median nerve* or *ulnar nerve*. Both nerves are superficial at the wrist.

Peripheral nerves may be stimulated unilaterally to test left- and right-sided pathways separately. For bilateral monitoring, left and right stimulation can be alternated during the same period of time in a method called asynchronous stimulation. Asynchronous stimulation allows for rapid data collection while still interpreting data with side-to-side specificity. Modern IOM equipment can average simultaneously from several sites using programmable protocols with delays between different stimulation sites.

Bilateral upper and lower SEP monitoring is used for some spine cases. Median or ulnar nerve stimulation is included in thoracic and lumbar cases as a means of monitoring for arm position or anesthesia-related changes. Ischemia secondary to hemodynamic events may also be detected by SEP monitoring from all extremities. Ulnar nerve monitoring also can help detect an incidental brachial plexus impairment resulting from patient positioning during long cases.

For cervical procedures, median or ulnar nerve pathways are the primary pathways

Table 6.1 SEP monitoring techniques

Stimulation
Lower extremity stimulation sites
Posterior tibial nerves at the ankle
Or peroneal nerves at the knee, e.g., in patients with peripheral neuropathy
Upper extremity stimulation sites
Median nerves at the wrist for intracranial cases and cervical cases C5 and above
Ulnar nerves at the wrist for spinal cases at or below C6
Stimulus intensity
Supramaximal (10% over intensity required to record maximal peripheral response)
Stimulus rate
5.1 per second per nerve, if tolerated with good peaks
Or slower if needed to obtain good peaks avoiding harmonics of 60
Recording
For lower extremity stimulations
Two cortical channels, CPi–CPc and CPz–Fpz
A cervical channel: CSp5–Fpz
For upper extremity stimulations
Two cortical channels, CPc–CPi and CPc–Fpz
A cervical channel: CSp5–Fpz
One peripheral channel: Erb's point ipsilateral, contralateral
Filters 30 and 3000 Hz, notch filter off, adjusting the filters as needed
300 trials per EP, more if needed

monitored. Because the ulnar nerves enter the spinal cord at a lower level, ulnar nerve monitoring is preferred for cervical cases at and below the C6 spinal level. PTN channels also are monitored in cervical cases for detection of a high thoracic or low cervical spinal cord injury. The four limb coverage also provides greater spinal cord protection from events such as hemodynamic changes.

Averaging

SEP data are low amplitude, often <1 μV. This amplitude is less than the surrounding background noise, which includes cerebral EEG activity. To find a reliable SEP measurement, data must be averaged. Averaging of low amplitude signals increases the signal-to-noise ratio (SNR) in a manner proportional to the square root of the number of trials. More trials result in better SNR. About 300 averaged recording trials often produce well-defined peaks.

Intensity

The correct way to determine the optimum stimulus intensity is to determine the intensity that produces the largest amplitude peripheral response and then add 10%. This is known as supramaximal stimulation and ensures that 100% of the nerve fibers are being recruited and that small changes in electrode resistance won't appreciably affect the recruitment percentage. Supramaximal stimulation will cause a 1–2 cm movement in the appropriate muscle groups in the absence of neuromuscular blockade. Median nerve stimuli produce thumb movement. Ulnar nerve stimuli produce fifth digit movement. PTN stimuli produce foot flexion, while peroneal nerve stimuli produce foot dorsiflexion. A stimulus artifact should be seen at time zero in recording channels, confirming that the stimulus is actually being delivered. Many modern IOM machines show current delivered and returned, and this also can be used to confirm stimulus delivery.

Electrodes

Stimulation electrodes can be needles, disks, or adhesive electrodes. An electrode pair consisting of a cathode and anode is secured over the nerve. The resistance between the electrodes and the skin should be <5 kΩ to ensure adequate stimulus delivery and avoid large stimulation artifact. Needle electrodes provide a low resistance and avoid resistance changes over long cases. For disk or adhesive electrodes, skin preparation with an abrasive is used to reduce electrical impedances. Patients allergic to citrus fruit may have a reaction to the skin preparation gel containing lemon. If using an

electrode paste, it should be free of calcium to avoid chemical burns from iontophoresis into the skin.

Rate

The repetition rate must strike a balance between rapid data collection and recording of a quality waveform. Typical repetition rates are between 2 and 5 stimulations per second. A complete data set can usually be obtained in a few minutes at these rates. Repetition rates >5 per second sacrifice data quality for more rapid collection. The amplitude of the peaks will decrease appreciably as rates increase above 5 pulses per second due to refractory times of the individual nerve fibers. Stimulation rates should avoid exact multiples of 60 Hz (or 50 Hz) to avoid line noise artifact.

Recording

Recording bioelectric signals involves optimization of several factors. At the beginning of a case, potentials should be optimized and set as baseline recordings suitable for comparing subsequent data during the procedure. Quality baseline recordings are essential to providing the surgeon with accurate data interpretation. Scouting for optimal baselines includes evaluating different recording sites, filter settings, and other parameters. A simple cookbook one-size-fits-all approach to SEP monitoring often leads to suboptimal recordings. The expertise of the monitoring team is in establishing the best recordings for each patient.

Recording Sites: General Comments

SEP recordings are made from successive sites along the DCML pathway. These recording sites are chosen to provide measurements from peripheral, spinal, subcortical, and cortical levels. In general, the active electrode is placed as near as possible to the anatomic generator, and a reference electrode is placed some distance away. The reference may be another scalp site or a non-cephalic site. Bipolar recording montages compare inputs between two nearby electrodes, while referential recording montages compare inputs between an active electrode near the anatomic generator and a much further placed reference electrode. The amount of electrical noise is proportional to the distance between the active and recording electrode as well as the distance between the anatomic generator and the active electrode. Cervical potentials are more susceptible to electrical noise because of the distance of the generator, yet these potentials are less affected by inhalation anesthetic concentrations due to the lack of synapses up to this point in the pathway. For this reason, they often are included in the recording montage despite their predisposition to noise.

The surgical field may make the preferred recording sites inaccessible. When this happens, it is necessary to scout for alternate recording sites that will yield the highest possible recordings. Neurosurgical craniotomies may displace scalp sites. Cervical surgery may displace cervical recording sites. Several nearby alternate sites may be tried.

Site Nomenclature

The International Federation of Clinical Neurophysiology's 10–20 System provides the accepted naming convention for scalp recording sites. The 10% extension of the 10–20 system [1] adds additional nomenclature. The EEG chapter in this book has further information on electrode nomenclature. For those unfamiliar with the naming conventions, a brief overview is given here. Electrode sites are named in a coordinate fashion with the first part of the binomial nomenclature indicating the anteroposterior position and the second part of the name indicating mediolateral position. A series of anteroposterior lines are named according to their position relative to certain brain features. The C-line runs generally along the central sulcus. The P-line is at the level of the parietal lobe. The line in between the C-line and P-line is the CP-line. Mediolateral positioning is named

relative to the lateral distance from the Z-line which runs along the vertex of the skull (midline). Odd numbers are to the left of the Z-line and even numbers to the right. The smaller the number, the closer to the Z-midline. For example, an electrode placed over the right postcentral gyrus near the hand area (lateral) would be CP4. The midline position would be named CPz. The location halfway between CPz and CP3 is known as C1. The letters "*i*" or "*c*" can replace the numbers when referring to general positions as either ipsilateral or contralateral, respectively.

Estimating recording sites by visual gross inspection, instead of measuring locations according to the 10–20 system, misplaces electrodes often by a centimeter or two. That misplacement may result in suboptimal recordings and poor ability to reproduce recordings if an electrode needs to be replaced after falling off.

SEP IOM also uses non-cephalic recording sites, e.g., over vertebral spines and at Erb's point. Erb's point is located above the clavicle, 2 cm lateral to the insertion of the sternocleidomastoid muscle. Sites over vertebrae are referred to by their spinal level, sometimes including the term Sp for *spine*. In that way, CSp5 is located over the fifth cervical spine's posterior spinous process.

Some recommended technical parameters are given in Table 6.1.

Lower Extremity SEP Recording Channels

Lower extremity SEP recordings are made from CSp5 and the scalp. The CSp5 channel monitors the cervical-brain stem activity, and the scalp channels monitor cortically generated peaks.

There is no single correct scalp recording site for the cortically generated peak of the lower extremity SEP. The cortical generator's dipole is oriented differently in different patients and can change with the depth of anesthesia. Principal sites for the active electrode include CP1, CP2, CP3, CP4, and CPz. The orientation of the neurons that generate the potential changes as the postcentral gyrus bends toward the midline. The orientation of the midline neurons that generate the cortical potential in response to lower extremity stimulation causes the dipole to project across the midline. This dipole projection results in a "paradoxical localization" of the potential over the scalp ipsilateral to limb stimulated. This is paradoxical in that the neurons generating the potential are located in the contralateral hemisphere (as indicated by DCML pathway anatomy). Common sites for the active electrode are CPi, CPc, and CPz.

Choosing a site for the reference electrode is also important. Scouting possible recording channels early in the case helps to find the best channels to monitor in that patient, although time may not permit this exercise. References may include the forehead, ear, mastoid, or the scalp location contralateral to the active electrode. Short distances between the active and reference electrodes (e.g., CPi–CPc) reduce noise but also may reduce peak amplitudes.

The subcortical peaks may be recorded over the spinous process of C5 (CSp5) with an ear, forehead, or contralateral shoulder as a reference. The subcortical peaks are less affected by anesthesia due to the lack of synapses at this point of the DCML pathway. Peripheral recording sites include the popliteal fossa or over the lumbar and thoracic vertebrae such as TSp12 or LSp1. Older and obese patients may have no recordable lumbar potentials as a normal variant.

Upper Extremity SEP Recording Channels

For upper extremity SEPs, recordings are made at the shoulder, cervical spine, and scalp. Scalp sites are generally optimum over the contralateral postcentral gyrus (CPc) with a forehead, ear, or mastoid reference. Subcortical peaks popularly are recorded from CSp5, earlobe, or mastoid with a reference located either at the forehead or contralateral Erb's point. An Erb's point channel (referenced to the contralateral Erb's point) can be used to test peripheral conduction and is useful for monitoring changes secondary to positional issues.

Filters

The typical low-frequency filter is set to 30 Hz and high-frequency filter 500–1500 Hz. This balances control over noise while maintaining most SEP peak characteristics. These settings reduce random amplitude fluctuations and some anesthetic-related variability [2]. Properly set filters will yield reproducible SEPs with minimum background variability in amplitude and latency.

Notch filters should not be used during SEP recording. The notch filter can cause a stimulus artifact with a decaying sinusoidal tail with peaks at 16.6, 33.3, and 50 ms. Those peaks easily can be mistaken for stable EPs at 16.6 or at 33.3 ms. This is called a ringing artifact.

Digital smoothing filters are available on most modern IOM equipment. They can distort the peak, possibly mixing artifact with a peak in ways that make interpretation more difficult. Excessive smoothing is to be avoided.

It is always recommended to eliminate background and environmental noise at its cause when possible, instead of masking the noise with filters. Scouting is undertaken to find channels less affected by noise. Sometimes changes can be made to filter settings, but with care to avoid the negative effects of such changes. These effects include changing the signal morphology as well as introducing a phase shift.

Primary Peaks

Lower Extremity SEPs

The P37 is the primary cortical peak generated by the somatosensory cortex. Often it is seen on the scalp ipsilateral to the leg stimulated at 37–45 ms after PTN stimulation at the ankle in normal patients. It is longer in taller individuals, the elderly, or those with pathology. The P37 generator lies in the vascular territory of the anterior cerebral artery. Figure 6.2 shows the lower extremity SEP peaks and nomenclature in a typical case.

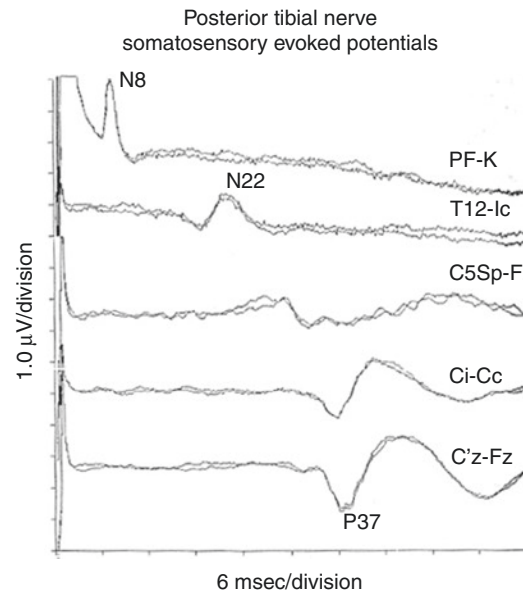

Fig. 6.2 Somatosensory-evoked potentials from posterior tibial nerve stimulation are shown. Typical peaks N8, N22, and P37 are noted. A cervical peak was also found. These peaks have normal latencies and amplitudes. (*PK* popliteal fossa, *K* knee, *T12* T12 spine, *Ic* contralateral iliac crest, *C5Sp* C5 spine. Reprinted with permission from Nuwer et al. [4])

The cervical peak is a far-field signal seen around 31 ms after stimulating the PTN at the ankle. The likely generator of this (N31) peak is the nucleus gracilis at the cervicomedullary junction. A trough following the cervical peak may represent conduction along the medial lemniscus or a thalamic potential. Amplitude and latency measurements for the cervical peaks are used especially when the cortical P37 is poorly suited for monitoring. Anesthetic has much less effect on the cervical peaks due to the absence of synapses from the point of stimulation, so the cervical peak is more stable when anesthesia effects are prominent. These subcortical potentials lie in the vascular territory of the vertebra-basilar complex.

The N22 peak is a negative potential around the T12 spine at approximately 22 ms after

stimulation. It is generated in the lumbar spinal cord, i.e., anatomically around the T12 spine. It represents the culmination of the peripheral pathway conduction up to and into the lumbar spinal cord. Peripheral peaks are monitored to clarify that decreased cortical potentials are due to a surgical problem rather than a problem with the stimulus or a positional issue. The popliteal N8 peak also could be used in a similar way.

Upper Extremity Peaks

The N20 is the cortically generated peak for upper extremity SEP IOM. The peak's amplitude and latency are measured, and used as criteria to monitor neurologic function. The peak arises from the primary somatosensory cortex on the postcentral gyrus contralateral to the side of stimulation. It is best seen recorded from an active electrode at CPc. The N20 lies in the vascular territory of the middle cerebral artery.

The subcortical peak is recorded with the same montage used for recording lower extremity subcortical potentials. The N13 cervical spinal cord peak arises from the mid-cervical spinal cord at the C5 level where the median nerve roots enter the spinal cord. For ulnar nerve stimulation, the peak arises from the sixth or seventh cervical spinal cord. This N13 peak is followed by a positive P14 peak generated by the nucleus cuneatus and its decusation of the medial lemniscus. Rostal to those peaks, an N18 arises from the thalamus. The N18 is often obscured by its proximity to the N20. For this reason, a CPi–EPc recording channel can be used to isolate the N18. These subcortical N13 and P14 potentials are in the vascular territory of the vertebra-basilar complex, and the N18 posterior communicating artery territory.

A peripheral N9 peak is recorded over the brachial plexus at Erb's point. The blood supply for this potential is the axillary artery. Figure 6.3 illustrates typical upper extremity SEP peaks and their nomenclature.

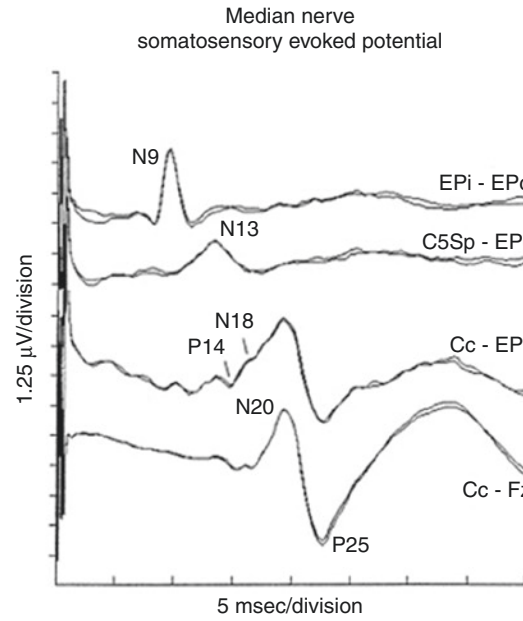

Fig. 6.3 Somatosensory-evoked potentials from median nerve stimulation are shown. Typical peaks are shown in each of four recording channels. The test is normal. (*EPi EPc* Erb's point ipsilateral, contralateral. Reprinted with permission from Nuwer et al. [4])

Interpreting Change

Characteristics of the SEP waveform including latency, amplitude, and area under the curve. These are useful to interpret changes from baseline. In order for any test to be useful for the purposes of IOM, it should have an adequately high sensitivity and specificity. When changes in latency and amplitude are used for SEP IOM, this test is nearly 100% sensitive and specific. This means that there are very few false positives or negatives with SEP monitoring. Typical alarm criteria for SEP IOM is a 50% decrease in amplitude and/or a 10% increase in latency [3, 4]. For very stable peaks, a criterion of 30% to 40% decrease may be used. When these thresholds are crossed, the monitoring team quickly assesses the reason for the change. Technical issues should be quickly resolved. Changes due to anesthesia should be documented and communicated with the surgical team and anesthesiologist. Surgical-

induced changes should be immediately reported to the surgeon as they may warrant intervention.

Anesthetic effects are one of the main reasons for an SEP IOM change. Inhalntion anesthetics, nitrous oxide, or bolus injections may reduce the amplitude of the SEP signal. Since anesthetic works primarily at synapses, cortical potentials are most susceptible to anesthetic effects, while subcortical and peripheral potentials remain relatively stable. *Anesthetic fade* refers to a gradual reduction in amplitudes during the first 30 min after induction and to a smaller extent over subsequent hours of a long case. Anesthetic fade is most common with inhalation anesthetics.

Preexisting impairment may magnify anesthesia effects (Fig. 6.4).

Technical problems should be ruled out when signals change. When a technical issue is suspected, it is important to distinguish between a stimulation and recording issue. Large increases in electrode impedance suggest a recording problem such as a dislodged electrode. Absence of a stimulation artifact or poor current return indicates that there is a problem with stimulus delivery. Another common recording problem is the introduction of electrical noise. In this case, the live (unaveraged) waveform should be viewed and the frequency band of the noise be identified. The first priority should be to find and eliminate the source of the noise. If that fails, changing the passband by adjusting filter settings may be required.

Perisurgical factors may also induce SEP data changes including hypothermia, hypotension, and hypoxia. Cooling can increase latencies. Cooling can be systemic, in a limb, or because of local irrigation. Substantial cooling can cause SEP cortical peak amplitude loss, even decreased to isoelectric

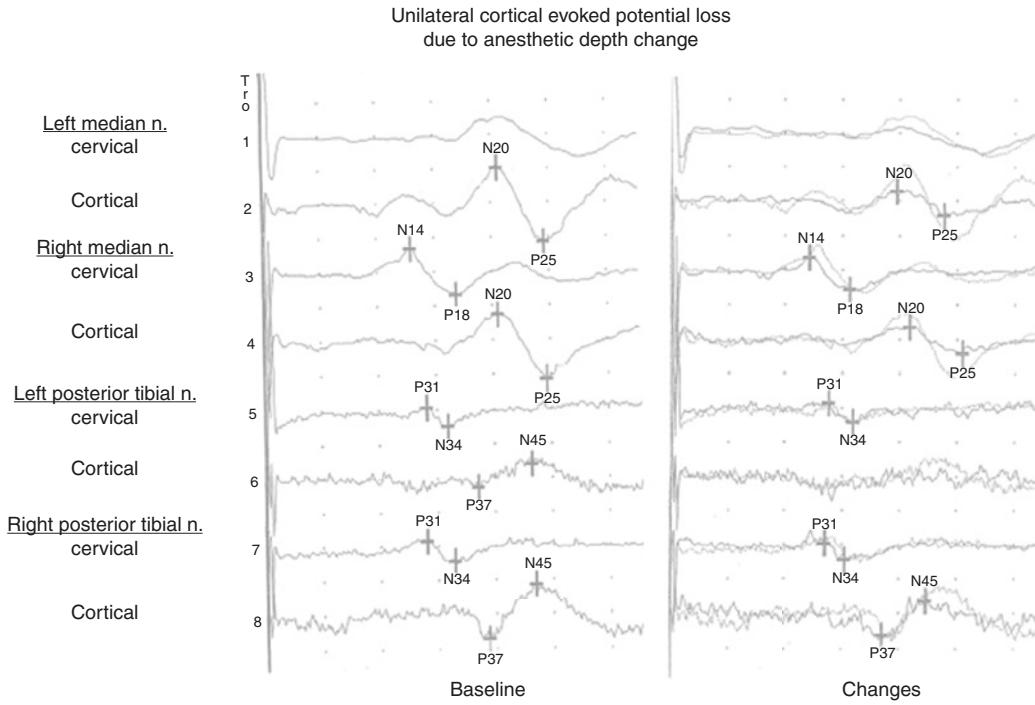

Fig. 6.4 The baseline testing shows a relatively attenuated left lower extremity cortical peak (*left* tracings). After an increase in anesthetic depth (*right* tracings), that channel no longer shows a reliable SEP (The baseline is superimposed on the newly acquired tracings at the *right*.) An anesthetic effect is the likely cause of the change, as suggested by both the preserved subcortical peaks for the affected pathway and somewhat attenuated cortical peaks in all other pathways. (From UCLA Department of Clinical Neurophysiology, with permission)

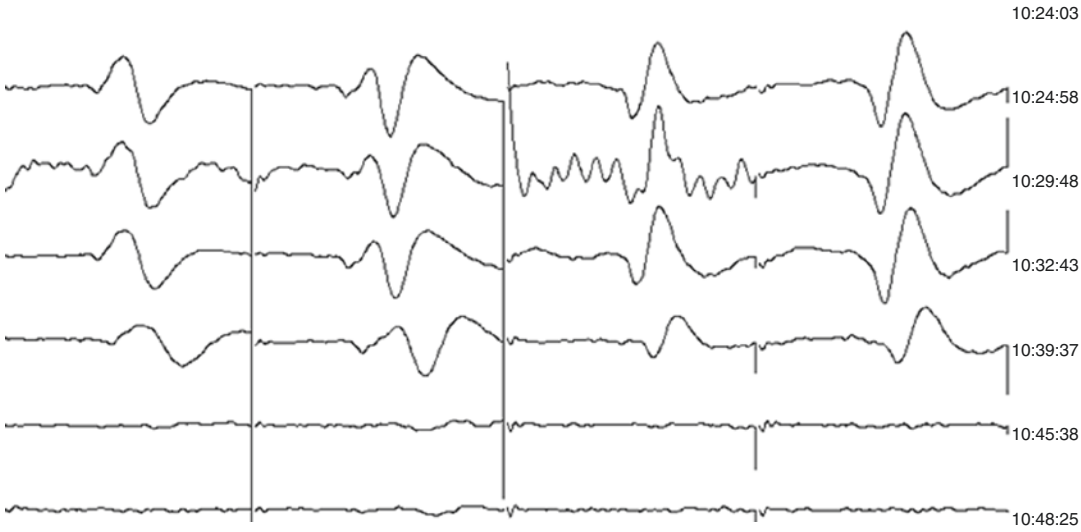

Fig. 6.5 Temperature effects on SEPs. Left and right median and left and right posterior tibial nerve SEPs are shown over 25 min as the patient's core temperature dropped from 34 to 20 °C. Time flows from top to bottom. Latencies increase, amplitudes decrease, and then the peak essentially disappears

recordings at temperatures below 22 °C (Fig. 6.5). Preexisting spinal cord compression may leave a patient especially sensitive to hypotension due to autonomic dystonia. Correlation of SEP changes with the anesthesia doses, the patient's temperature, and blood pressure will help determine the cause of change and a solution. It should be mentioned that just because a change is not deemed surgical does not make it clinically insignificant. A change resulting from hypotension indicates that the brain is not being adequately perfused. It is necessary to communicate this to the surgeon and anesthesiologist so that corrective action may be taken.

Surgical problems also cause changes, which is likely the reason you were asked to monitor the case to begin with. Types of surgical issues that can cause data changes include direct blunt trauma, excessive retraction or compression, stretching of structures, vascular insufficiency, vasospasm, embolus, thrombus, or other clinical problems. Not all amplitude decreases are clinically significant, meaning not all will result in a deficit. The likelihood that an amplitude reduction predicts an adverse outcome increases as the amplitude decrease worsens and the longer the change persists. Early identification of changes leading to prompt intervention is critical to preserving function. A 50–80% transient amplitude decrease for only a few minutes poses a small-to-modest risk of postoperative neurologic deficits, especially if the SEPs return promptly to baseline values following intervention. Higher risk is incurred with abrupt changes, complete loss, and persistent attenuation. The gravest situation is the abrupt, persistent, complete loss of previously easily detected SEPs. Even an abrupt persistent loss does not always predict impairment. The risk in that case is about 50–75% [4]—a deficit is not a foregone conclusion.

Stable intraoperative SEPs are highly predictive of a good neurological outcome. A patient will have a neurologic injury despite the preservation of intraoperative SEPs in fewer than 0.1% of cases (Table 6.2). This degree of sensitivity and specificity makes SEPs the gold standard for intraoperative spinal cord monitoring. IOM-prompted surgical interventions are successful at reducing postoperative neurological deficits. The use of IOM reduces paraplegia by 60% for spinal surgery [4].

Table 6.2 Neurologic outcome prediction rates for SEP monitoring in spinal surgery

False-negative rate	
Neurologic postoperative deficits despite stable SEPs	
Definite	0.06%
Total	0.13%
False-positive rate	
No neurologic deficits despite SEP changes	
Definite	0.98%
Total	1.51%
True-positive rate	
Neurologic deficits predicted by SEP changes	
Definite	0.29%
Total	0.42%
Neurologic deficits	
False negative plus true positive	
Definite	0.36%
Total	0.55%
Sensitivity	92%
Specificity	98.9%
Positive predictive value	42%
Negative predictive value	99.93%

These data are from a large multicenter US outcome study of SEP spinal cord monitoring organized through the Scoliosis Research Society. Note the rate of definite false-negative cases is low (0.06%). The very high negative predictive value here indicates the high reliability of the monitoring when the SEP remains normal and stable. The outcome survey report [5] discusses in detail these data and related assumptions

Finding the Motor Cortex

In addition to monitoring, SEPs can be used to test for the location of motor cortex. The median nerve SEP stimulation technique is used. Recording is from a 1 by 8 strip of cortical electrodes laid directly onto the exposed cerebral cortex. A nearby reference electrode is placed at a neutral site such as on dura or muscle. The N20 peak appears at the primary somatosensory cortex on the posterior edge of the central fissure. By determining the N20 location, one can deduce that the next more anterior gyrus is the motor cortex. The strip electrode may be moved several times to find the thumb level of sensory cortex that corresponds to the median nerve stimulation site.

Clinical Indications

There are many indications for the use of SEPs in the operating room [6]. The most common use is for spinal cord monitoring in cases involving scoliosis, cervical myelopathy, fractures, tumors, and other disorders that put the spinal cord at risk during surgery. SEPs also are used to monitor the intracranial portions of the somatosensory pathways. For example, SEPs are useful for monitoring the brain stem during surgeries to remove cerebellopontine angle tumors, during cranial nerve microvascular decompression procedures, brainstem and cerebellar tumor resections, aneurysm clippings or coilings, and decompression of Chiari malformations. SEPs are used to monitor the internal capsule and cerebral cortex for ischemia during carotid endarterectomy, brain tumor removal, arterial-venous malformation resection, aneurysm clipping, epilepsy surgery, and other procedures placing the cerebral cortex at risk.

In each case, similar SEP parameters and criteria for change are used. The nerve chosen for stimulation may differ based on the objective of the procedure. Median and posterior tibial nerve SEPs are monitored most often. The peroneal nerve at the knee may be substituted for the posterior tibial if the patient has a peripheral neuropathy or has an amputation below the knee. The ulnar nerve is used in place of the median in spine surgery at or below C6 to give better coverage of the whole cervical spine. The ulnar nerve is also most vulnerable to arm positional injury, so monitoring is indicated for the ulnar nerve SEPs during thoracic or lumbar cases.

For intracranial cases, the choice of SEP monitoring should depend on the vascular territory at risk. Lower extremity SEPs are important to monitor for cases involving risk to the vascular territory of the anterior cerebral artery. Upper SSEPs monitor the territory of the middle cerebral artery. For intracranial cases, the recording

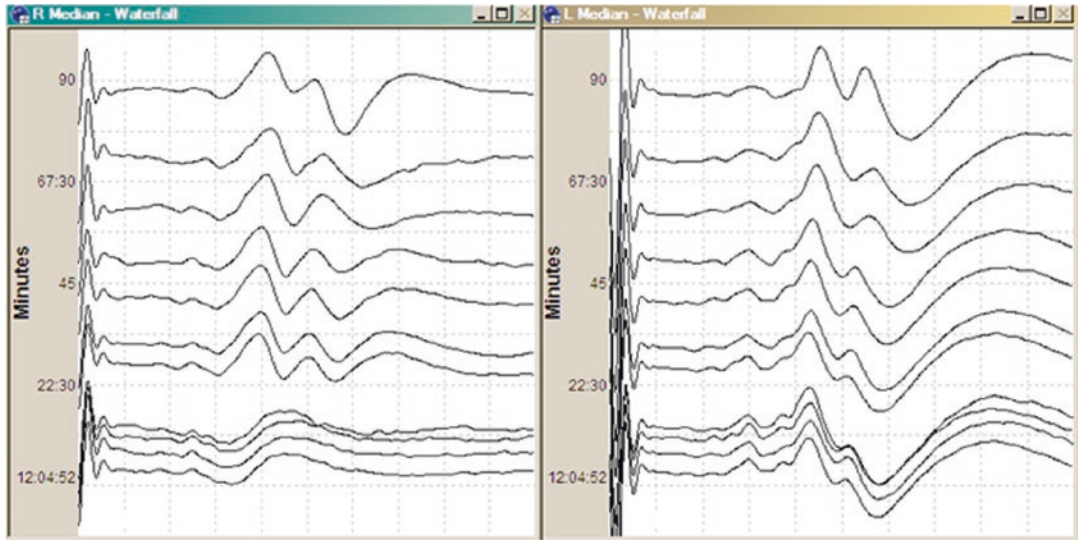

Fig. 6.6 A 68-year-old woman during left internal carotid artery aneurysm clipping after a subarachnoid hemorrhage complicated by arterial dissection. During surgery, the right median (shown) and posterior tibial (not shown) SEPs' cortical peaks for the left hemisphere were lost within 20 min of clipping, at a time when further aneurysmal bleeding was encountered. Time reads from the top downward (later tracings at the *bottom*). Ninety minutes of the monitoring is shown around the time of clipping. Note how the N20 peak is replaced by a lower amplitude far-field potential generated at the thalamic or high brain stem level, so the tracing is not flat. At the same time, the contralateral side remains stable. This patient suffered a thrombosis in the middle cerebral artery territory ischemic infarct despite the SEP alarm

electrodes may need to be moved away from the craniotomy flap. Figure 6.6 shows an example of an SEP recorded from alternate scalp locations during an aneurysm clipping.

If SEP IOM is being used to protect a peripheral nerve, such as the sciatic, then the anatomy will dictate the proper stimulation sites. For example, when monitoring sciatic nerve, the peroneal portion that is most at risk during hip replacement surgery. In the case in which the sciatic nerve is at risk, it may be appropriate to monitor both the posterior tibial and peroneal nerves.

SEP IOM remains the modality best supported in the literature. In a formal assessment process, the American Academy of Neurology and the American Clinical Neurophysiology Society jointly concluded and recommended that IOM is established as an effective means to predict an increased risk of the adverse outcomes of paraparesis, paraplegia, and quadriplegia in spinal surgery based upon four Class I and seven Class II studies. Surgeons and other members of the operating team should be alerted to the increased risk of severe adverse neurologic outcomes in patients with important IOM changes [7]. A large multicenter study of spinal cord SEP monitoring showed a 60% decrease in paraplegia and paraparesis associated with monitoring [4]. Validity measures and neurologic deficit rates from that study are shown in Table 6.2.

Sala et al. [8] studied motor outcomes for intramedullary spinal cord tumor surgery. Historical controls were used from the time prior to the adoption of IOM. If IOM showed changes, myelotomy was moved to a different location along the tumor or temporarily stopped. Sala

measured the McCormick grade of weakness for patients with EP monitoring, and compared those results to patients without EP monitoring. For the patients with IOM, the preoperative to postoperative change in McCormick grade of weakness was +0.28. For the patients without IOM, the preoperative to postoperative change was −0.16. The difference between groups was significant ($p < 0.002$).

Many animal studies also support the validity of IOM. They show that raising an alarm at a suitable point in time gives the surgeon enough time to intervene and avert a postoperative neurological deficit in many patients. For that reason, IOM SEP is considered clinically useful by most and should be used when there is a reasonable risk of neurological injury from surgery.

Questions and Answers

1. The best tradeoff for SEP stimulation rate for a teenager is often around.
   (a) 3 per second
   (b) 5 per second
   (c) 7 per second
   (d) 9 per second
2. When cortical SEPs are low amplitude, tactics to improve the signals' amplitude include
   (a) Faster stimulation rates
   (b) Lower low filter setting
   (c) A smaller sample size to produce EPs more quickly
   (d) Turning on the notch filter
3. In the 10–10 system, electrode site CP2 is located
   (a) Halfway between Cz and P4
   (b) Halfway between Cz and C4
   (c) Halfway between Pz and P4
   (d) Halfway between C4 and P4
4. The peripheral recording site Erb's point is at
   (a) 5 cm above the mid-clavicle just lateral to the sternocleidomastoid
   (b) 2 cm above the mid-clavicle just lateral to the sternocleidomastoid
   (c) Above the clavicle, 2 cm lateral to the insertion of the sternocleidomastoid
   (d) Above the clavicle, 5 cm lateral to the insertion of the sternocleidomastoid
5. The most likely location for the best amplitude of the P37 peak for right posterior tibial SEP testing is
   (a) C1'
   (b) C2'
   (c) Cz'
   (d) CPz
6. Recording site PF is at
   (a) Posterior frontal
   (b) Popliteal fossa
   (c) Parietofrontal
   (d) Parafrontal
7. The most commonly used criterion for alerting a drop in posterior tibial SEPs is:
   (a) 10% amplitude loss or 2 ms latency increase
   (b) 30% amplitude loss or 3 ms latency increase
   (c) 50% amplitude loss or 4 ms latency increase
   (d) 70% amplitude loss or 6 ms latency increase
8. The greatest amplitude decreases in cortical SEPs are commonly associated with.
   (a) Too high a setting of the stimulus intensity
   (b) Cooling to 32 °C
   (c) MAC use of inhalation anesthetics
   (d) Too low of a low filter setting

Answers

1. (b)
2. (b)
3. (a)
4. (c)
5. (b)
6. (b)
7. (c)
8. (c)

References

1. Nuwer MR. Recording electrode site nomenclature. J Clin Neurophysiol. 1987;4:121–33.
2. Nuwer MR, Dawson E. Intraoperative evoked potential monitoring of the spinal cord: enhanced stability of cortical recordings. Electroencephalogr Clin Neurophysiol. 1984;59:318–27.

3. Nuwer MR, editor. Evoked potential monitoring in the operating room. New York: Raven; 1986.
4. Nuwer MR, Dawson EG, Carlson LG, Kanim LEA, Sherman JE. Somatosensory evoked potential spinal cord monitoring reduces neurologic deficits after scoliosis surgery: results of a large multicenter survey. Electroencephalogr Clin Neurophysiol. 1995;96:6–11.
5. Nuwer MR, Aminoff M, Desmedt J, Eisen AA, Goodin D, Matsuoka S, et al. IFCN recommended standards for short-latency somatosensory evoked potentials. Electroencephalogr Clin Neurophysiol. 1994;91:6–11.
6. Nuwer MR. Intraoperative monitoring of neural function. In: Handbook of clinical neurophysiology, vol. 8. Amsterdam: Elsevier; 2008.
7. Nuwer MR, Emerson RG, Galloway G, Legatt AD, Lopez J, Minahan R, et al. Intraoperative spinal monitoring with somatosensory and transcranial electrical motor evoked potentials. Neurology. 2012;78:585–9.
8. Sala F, Palandri G, Basso E, Lanteri P, Deletis V, Faccioli F, et al. Motor evoked potential monitoring improves outcome after surgery for intramedullary spinal cord tumors: a historical control study. Neurosurgery. 2006;58:1129–43.